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# EFFECT OF SKIMMER INTERACTION ON THE PROPERTIES OF PARTIALLY CONDENSED MOLECULAR BEAMS

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ARO, Inc.

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# NOTICES

# EFFECT OF SKIMMER INTERACTION ON THE PROPERTIES OF PARTIALLY CONDENSED MOLECULAR BEAMS

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## FOREWORD

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## ABSTRACT

Through the extensive use of cryopumping in the source, collimation, and test chambers of a molecular beam test facility, it has been possible to identify some of the factors affecting beam intensity in noncondensed and condensed flows. For noncondensed flows, the positioning of a warm conical skimmer in front of a cryopumped end wall does not appear to result in any significant skimmer interference effects on beam intensity. However, the location of a warm annular surface with inner and outer diameters of 14.5 and 23 cm, respectively, at the cryopumped end wall resulted in a significant attenuation of the incident beam intensity. This indicates that end wall scattering is a significant factor in determining molecular beam performance. With the onset of condensation, it has been shown that nonpumping skimmers and end walls reduce the incident beam intensity. This attenuation results from condensed clusters impacting on the warm surfaces and the resultant debris reflecting into the incident beam. However, for beams with significant condensation, the total beam intensity is not affected as greatly. It is postulated that for source conditions where there is significant condensation, the incident beam attenuation will not be as great since the beam is composed of large clusters (possibly liquid droplets or crystals) that are not as easily scattered by the reflected cluster debris. Measurements of gas velocity in a condensed flow indicate that a nonpumping surface placed in the beam affects not only beam intensity but also the beam velocity.

## CONTENTS



## APPENDIX
## ILLUSTRATIONS

## NOMENCLATURE

| | |
|---|---|
| $d$ | Beam orifice diameter |
| $T_o$ | Stagnation temperature |
| $x_s$ | Source-to-skimmer distance |

# SECTION I
# INTRODUCTION

Over the past 15 years or so, a considerable theoretical and experimental effort has been devoted to the problem of producing high-intensity molecular beams. These beams have been formed by skimming from the supersonic core of a free-jet expansion. Many experimental studies have been devoted to determining the effect of the skimmer upon the molecular beam properties. One of the more recent systematic studies of this type has been made by Bossel (Ref. 1). This study summarizes the effects of a room temperature conical skimmer upon the characteristics of a molecular beam. For certain beam source conditions, Bossel was able to reduce the effect of the skimmer to the point where the measured beam flux approaches the idealized theoretical value.

For conventional nozzle-skimmer configurations used to produce molecular beams, there are at least two generally accepted beam scattering mechanisms: (1) When the skimmer is operated in the continuum flow regime, there is a reduction in the total beam intensity because of shock and viscous effects, resulting in a distortion of the molecular velocity distribution, and (2) when the skimmer is placed downstream in the rarefied flow, there is scattering of the beam which occurs when the background pressure in the source chamber is high.

Anderson et al. (Ref. 2) and Brown and Heald (Ref. 3) have shown that by replacing the conventional 300°K skimmer with a cryogenically cooled skimmer the beam intensity at high source pressures could be significantly increased. Brown and Heald (Ref. 3) suggest, on the basis of the work of Mayer et al. (Ref. 4), that any viscous effects may be related to shock waves and boundary layers on the skimmer and are virtually eliminated when this surface is cryogenically cooled. Brown and Heald (Ref. 3) have also shown that the background gas scattering problem was significantly reduced by lowering the background pressure in the source chamber. This reduction in pressure was achieved by the extensive use of cryopumping in the source chamber. The use of a 77°K skimmer pumping surface limited the gases that could be pumped with this system (Ref. 3). Ruby (Ref. 5) improved the molecular beam system considerably by replacing the 77°K liquid-nitrogen-cooled skimmer with a 20°K gaseous-helium-cooled one. With this skimmer configuration, Ruby was able to produce argon molecular beams having an intensity of $1.0 \times 10^{21}$ molecules/steradian/sec at source pressures of 2.5 atm. This represents a factor of ten increase over that obtained with a conventional 300°K conical skimmer (Ref. 5).

At some point in the flow field of a free-jet expansion, flow conditions in the expansion and the surrounding gas are such that a normal shock (or Mach disk) is formed in the flow. Upstream of the Mach disk, the flow is assumed to be isentropic. To produce an intense molecular beam, it is necessary to position the skimmer upstream of the Mach disk. It has been shown that the location of the Mach disk is a function of source orifice diameter and the ratio of source to background pressure in the source chamber. In conventionally pumped molecular beam facilities, the background gas pressure is usually of such a magnitude that the Mach disk is located at less than 100 orifice diameters from the source. This source chamber pumping limitation has limited the operation of the conventional 300°K conical skimmer to the near continuum flow regime. Also, the high pressures in the source chamber have resulted in significant attenuation of the beam as a result of background gas scattering. Ruby (Ref. 5) minimized the effect of background scattering by using a surrounding 20°K cryoliner in the source chamber.

A study of Ruby's work (Ref. 5) indicated that the effects of a 300°K skimmer on argon beam intensity were dependent upon the degree of condensation that existed in the flow. Prior to condensation, a 300°K conical skimmer, located approximately 600 orifice diameters from the source, produced almost identical values of beam intensity to that obtained with a 20°K skimmer. At high source pressures (approximately 10 atm), where considerable condensation was believed to exist, there was little difference in the total beam intensity obtained with both types of skimmers. In the intermediate source pressure range (0.2 to 10 atm), considerable differences in beam intensity were observed. At a source pressure of approximately 2 atm the 300°K skimmer attenuated the beam by a factor of 25. Golomb et al. (Ref. 6) discuss the various interpretations that have been made of the characteristic local maxima and minima that occur in curves of beam intensity plotted as a function of source pressure for a molecular beam formed with a 300°K conical skimmer.

In the present investigation, some modifications were made to the chamber used by Ruby (Ref. 5) such that the effects of condensation on the properties of molecular beams formed with 20°K and 295°K skimmers could be determined.

## SECTION II
## APPARATUS

The aerodynamic molecular beam chamber has been fully described in Ref. 3. Several modifications have been made to the chamber to improve operational flexibility. A schematic of the modified molecular beam system is given in Fig. 1, Appendix.

A schematic of the molecular beam source is shown in Fig. 2. The test gas flows through the center tube which vents into a settling chamber before passing through the orifice. The heating (or cooling) fluid is passed through two tubes concentric with the gas supply tube. The source is over 1 m long, which together with the settling chamber should give the test gas sufficient time to accommodate to the temperature of the circulating fluid. The temperature of the source gas is measured with a copper-constantan thermocouple located in the gas flow in the source settling chamber. Temperatures in the range 180 to 430°K are achieved as follows: (1) For 180 to 250°K, liquid nitrogen is circulated through a reservoir containing Freon® MF; the nitrogen flow rate is adjusted until the desired temperature is achieved in the Freon, which is then pumped through the source tube. (2) For 280 to 300°K, water is pumped through the source tube. (3) For 350 to 430°K, gaseous nitrogen is passed through a resistance-heated stainless steel tube and then through the source tube. Source orifices of various diameters were drilled in 0.005-cm stainless steel shim stock silver-soldered to the orifice insert (Fig. 2). These orifices were honed and polished until they were acceptably smooth and circular (Fig. 3). In the present series of tests, four orifice diameters were used: 0.0147, 0.0343, 0.0386, and 0.1245 cm.

Two skimmers were used in the present study. One was a 1.27-cm-diam circular opening in a 20°K gaseous-helium-cooled stainless steel plate. This stainless steel plate was mounted directly to the 20°K gaseous-helium-cooled cryoliner mounted from the source chamber bulkhead. The other was a 300°K conical skimmer mounted on a rotary arm (located 7.5 cm upstream of the 20°K skimmer) such that it could be positioned on the beam centerline or moved completely out of the beam. This skimmer had an inlet diameter of 0.4 cm, a total internal angle of 60 deg, and a total external angle of 80 deg.

A collimator consisting of a 0.4-cm circular opening in a 20°K gaseous-helium-cooled stainless steel plate was located 41 cm downstream of the 20°K skimmer.

A schematic of the modulated beam detection system is shown in Fig. 4 and a detailed description is given in Ref. 7. It consists of (1) a mechanical beam chopper, (2) a quadrupole mass spectrometer (2 to 600 AMU), and (3) a lock-in (narrow bandpass) amplifier. Downstream of the collimator the beam was further shaped by a 0.16-by-0.16-cm-square opening in a 0.005-cm stainless steel plate located in front of the chopping wheel. A photo-etching technique was used to make 20 equally spaced 1.9-by-0.16-cm slots in the 0.005-cm stainless steel wheel. The chopped molecular beam entered the ionization chamber of the mass

spectrometer. The ionized molecules were deflected 90 deg and drawn through a circular hole at the entrance of the quadrupole section. The ionizing energy and current (electron impact energy) was kept at 90 v and 0.2 ma throughout the experiments; the extractor, focus, and ion energy voltages were kept at 10, 135, and 22 v, respectively. The multiplier signal was fed directly into a field-effect-transistor (FET) source follower, which serves to match the high impedance of the electron multiplier output to the coaxial cable leading to the amplifier outside the chamber. The amplifier was a lock-in type, acting as a band-pass amplifier centered on the chopper frequency. A light and photocell mounted at the chopper wheel provided the reference signal to the amplifier. A 0.16-by-0.16-cm-square collimator was mounted on a rotary arm 3.7 cm upstream of the mass spectrometer ionizing section. It could be positioned either on the molecular beam centerline or completely out of the beam.

A detailed description of the velocity detection system (Fig. 5) is contained in Ref. 5. After passing through the chopper wheel, the molecules spread according to their velocity distribution. The quadrupole section of the mass spectrometer was tuned to the mass number of interest, and the resulting ion current was amplified by an electron multiplier. This signal was then processed in a Princeton Applied Research Corporation Model TDH-9 waveform eductor, and the resulting signal was displayed on an oscilloscope and photographed.

The velocity corresponding to the time of maximum signal is the most accurately determined flow property because the flight distance and time can be measured directly. For high speed ratio beams, this velocity is a good approximation to the mean velocity of the beam. In the present investigation, the variation of this velocity with source diameter, pressure, and temperature was considered. No attempt was made to determine the static temperature from the velocity profile. For both of the above systems, the mass spectrometer was mounted such that it could be rotated about the center of the ionizing region. Thus, measurements could be made with the axis of the quadrupole section normal to and parallel to the axis of the molecular beam.

The total incident beam intensity was measured with two detection systems: (1) a miniature ionization gage was positioned on the beam centerline; (2) a modulated beam detector system which consisted of the ionizing section of the EAI mass spectrometer coupled directly to a magnetic strip electron multiplier (total beam velocity measurements were also made using this detector).

# SECTION III
# DISCUSSION OF EXPERIMENTAL RESULTS

## 3.1 INDICATORS OF CONDENSATION IN A FREE-JET EXPANSION

With the onset of condensation in a free-jet expansion, the following processes would be expected to occur as the source pressure is increased: (1) formation of molecular clusters, dimers, and trimers; (2) appearance of liquid droplets; and (3) formation of crystals. Audit (Ref. 8) has performed electron diffraction analyses of the particles existing in condensed supersonic molecular beams for various gases. In these studies, he reports on the identification of monomers, dimers, liquid droplets, and crystals. The source pressures at which these phases are identified in an argon flow are shown in Fig. 6. Also shown in Fig. 6 for similar source conditions are (1) the results of measurements of total monomer, dimer, trimer, and tetramer beam intensity and monomer velocity obtained in the present investigation; (2) total beam intensity measurements (Ref. 9); and (3) characteristic cluster size measurements (Ref. 10). In the present study, the pressure at which the monomer and total beam deviate and the monomer velocity increases are in reasonable agreement with Audit's observations.

Ruby (Ref. 5) observed a velocity variation of the form shown in Fig. 6. He suggested that this increase in velocity resulted from the addition of the heat of condensation to the flow. Sherman (Ref. 11) has shown theoretically that an increase in gas velocity would be expected after condensation has occurred. In the present study, it has been assumed that either of these characteristics (velocity increase or deviation of the total and monomer beams) is indicative of condensation in the flow.

## 3.2 BEAM INTENSITY MEASUREMENTS

Bossel (Refs. 1 and 12) has indicated that molecular beam intensity can be attenuated by scattering from the skimmer surface and by scattering from the end wall to which the skimmer is attached. Of these two factors, scattering from the end wall appears to be the most significant. The significance of end wall scattering has been confirmed by Campargue (Ref. 13) and Singh (Ref. 14).

Total beam intensity measurements for some skimmer and end wall configurations obtained with a carbon dioxide beam are compared in Fig. 7. Measurements have been made which show that the form of total

beam intensity variation with source pressure does not change significantly for $200 \lessapprox x_s/d \lessapprox 1000$ for the present data, and $40 \lessapprox x_s/d \lessapprox 120$ for Ref. 3. Thus, it is reasonable to assume that a comparison of the present data with those of Ref. 3 can be made. It is felt that the comparison is not significantly affected by the differences in the source-to-skimmer separation distances of the two sets of data.

For source pressures where there is no gross evidence of condensation in the flow ($p_o < 150$ torr, derived from the velocity variation, Fig. 7), there are differences in the total beam intensity levels for the configurations shown in Fig. 7. A comparison of the present data obtained with a 20°K skimmer and a 295°K skimmer located in front of the 20°K skimmer suggests that over this source pressure range any scattering of incident beam molecules by molecules backscattered from the skimmer is negligible. Thus, it seems reasonable to suggest that the observed beam attenuation for the other configurations is attributable to either end wall scattering or background gas scattering. But because the chamber pressure was low in both investigations ($< 10^{-4}$ torr), it is suggested that background gas scattering had a negligible effect upon beam intensity. Thus, scattering from the end wall appears to be the dominant process for attenuating these noncondensed beams. There is reason to suspect that the plate used to mount the 77°K cooled skimmer, used in the studies reported in Ref. 3, was not fully cooled to 77°K, which could have resulted in some end wall scattering effects.

After the onset of condensation, the total beam intensity decreases to a minimum value and then increases rapidly with increasing source pressure for those configurations most affected by end wall scattering. Leckenby et al. (Ref. 15) have suggested that when large condensed clusters strike a surface they are destroyed and there is a liberation of single molecules. When large clusters strike a warm skimmer or end wall, regions of locally high monomer intensity will be formed which will scatter the light molecular species in the incident beam. With increasing source pressure, the condensed clusters will grow to such a size that they are not significantly scattered by this monomer cloud. At this point, the total beam intensity will increase with increasing source pressure. These events are more clearly illustrated in the argon data shown in Fig. 8. Before condensation, it can be seen that skimmer interaction is negligible and that beam attenuation results primarily from end wall interference. To illustrate the magnitude of the end wall interference, a 295°K ring having inner and outer diameters of 14.5 and 23 cm, respectively, was mounted concentric with the 20°K skimmer (configuration C, Fig. 8). It can be seen that scattering from this surface significantly attenuated the beam intensity. The degree of attenuation

is almost identical to that observed for the warm skimmer and end wall (configuration D). The source pressure at which the minimum in total beam intensity occurs for the warm skimmer and/or end wall is approximately the same for configurations B, C, and D. Also, at the maximum source pressure of this study the total beam intensity for configurations B, C, and D have approached to within 40 to 50 percent of that of configuration A. At these high source pressures, the molecular beam is comprised of such large particles that beam attenuation by skimmer and end wall interference is significantly reduced.

Before condensation ($p_o < 400$ torr), the warm skimmer and end wall effects that have been discussed earlier with regard to total beam intensity (Figs. 7 and 8a) affect monomer beam intensity measurements in a similar manner (Fig. 8b). The monomer intensities obtained with configurations A, B, and D were obtained with the mass spectrometer system shown in Fig. 4. A comparison of these measurements indicates that the monomer intensity decreases rapidly with increase in end wall and skimmer interference effects. These measurements support an earlier suggestion that end wall and skimmer interference effects would be very effective scatterers of incident beam monomers.

The data obtained for configuration C do not appear to be consistent with those obtained for configurations A, B, and D. There is good agreement between the total beam intensity measurements for configurations C and D, and for this reason a similarity in monomer beam intensity would be expected. One significant difference in the experimental apparatus used with skimmer configuration C was that a new and more sensitive multiplier was used in the mass spectrometer. Because of the improved sensitivity of the mass spectrometer, beam modulation was not considered necessary, and the chopper wheel was removed from the system. The noted inconsistency in the monomer signal confirmed a growing suspicion that when condensation is present in the molecular beam, the chopper wheel may attenuate on the mass spectrometer signal.

In order to further test this hypothesis, a 0.16-by-0.16-cm collimator (electroformed in stainless steel shim stock similar to the chopper wheel) was mounted on a remotely positionable arm such that it could be rotated into the beam and aligned precisely with an identical collimator orifice located at the chopper wheel. In this position, it was 3.7 cm in front of the mass spectrometer ionizing section and 34.3 cm from the chopper wheel. A small degree of radial spreading would be expected as the beam pulse traverses the distance between these two collimators. Therefore, if scattering from such surfaces located so far downstream is possible, then the large clusters in the beam will

impinge on the second collimator and result in a monomer cloud in front of this collimator. Monomer and dimer intensity measurements are compared with the collimator in and out of the beam in Fig. 9. It can be seen for conditions where there are large clusters that there is an attenuation of the beam when the second collimator is positioned in the beam. This supports the earlier suggestion that scattering at the chopper wheel collimator entrance can attenuate the incident beam monomer intensity. The degree of attenuation is likely to be greater at the entrance to the first collimator because the beam incident on this surface has a considerably larger cross section than that impinging on the second collimator. Therefore, the monomer beam intensity obtained with configurations A, B, and D may have been attenuated by the chopper collimator.

It is readily apparent from a consideration of Figs. 8b and 9 that dimer intensity measurements are affected by interference. The variation of dimer intensity with increasing source pressure is interference-dependent to such a degree that attempts to define the kinetics of dimer growth from such measurements are open to question (Refs. 16 and 17).

Earlier studies of skimmer interaction effects on beam intensity have largely been confined to skimmer-source distances of less than 200 source diameters. In the present study, this distance has varied from 150 to 3500 source diameters.

A comparison of total beam intensity for argon, carbon dioxide, and nitrogen flows for both warm and cold skimmers is made in Fig. 10. The distance between the source and the total beam intensity detector was held constant for both skimmers. It is evident from this comparison that the skimmer effect at source pressures where there is no condensation appears to be dependent upon the beam gas. For argon, the present data and those of Ruby (Ref. 5) demonstrate that at low source pressures the warm skimmer does not result in a significant reduction in incident beam intensity. For nitrogen and carbon dioxide, there is a 50-percent reduction in incident beam intensity with the warm skimmer. At least two reasons can be given for the reduction in beam intensity: (1) real differences in the expansion characteristics of monatomic, diatomic, and triatomic gases; and (2) a misalignment of the warm skimmer with the beam. A strong argument against skimmer misalignment can be made by the fact that the reduced beam intensity was produced by just changing the gas specie. Any attempt to increase the intensity of the $CO_2$ and $N_2$ beams by adjustment of the source and skimmer locations resulted in a further decrease in intensity, thus indicating that they were already located at their optimum positions. The results of tests with a small orifice at large source-skimmer

separation distances are shown in Fig. 11. Rotating the warm skimmer into the beam for a source-cold skimmer separation distance of $x_s/d = 1730$ indicates that before condensation there is a small reduction in beam intensity of approximately 10 percent. Before condensation, there is a relatively small change in the form of the variation of beam intensity with source pressure indicating a negligible skimmer interaction effect. When the separation distance is increased to $x_s/d = 3460$, there is a 60-percent reduction in beam intensity with no indication of a skimmer interaction effect (since the variation of beam intensity with source pressure is independent of type of skimmer used). It is apparent from a consideration of the carbon dioxide data shown in Figs. 10 and 11 that warm skimmer effects on beam intensity may be a function of source diameter and the source skimmer distance.

There is a significant difference in the form of the total beam intensity variation with source pressure for the large source diameter (Fig. 12) and for the two smaller sources (Figs. 10 and 11). A possible reason for this difference is a breakdown in the pumping efficiency of the 20°K skimmer because of too high an incident beam intensity at the skimmer surface. Increasing the separation distance, $x_s/d$, varies the incident beam flux at the skimmer, based on the assumption that beam intensity varies as $(x_s)^{-2}$.

For the test conditions shown in Fig. 12, the incident beam flux at the skimmer changes by a factor of ten. If the incident beam flux was so large that there was a breakdown in pumping at the skimmer, then increases in the incident beam flux would result in an increase in intensity of the backscattered molecules. It has been shown (Fig. 8a) that any increase in the number of backscattered molecules results in a decrease in the incident beam intensity. For the present test conditions (Fig. 12) the form of the beam intensity variation with source pressure is essentially independent of incident beam flux at the skimmer, indicating that there is not a breakdown in skimmer pumping. To confirm that this was not a result of a breakdown in skimmer pumping, larger local beam intensities were produced at the skimmer surface by moving a 0.0386-cm-diam orifice close to the skimmer, i.e., $x_s/d \lessapprox 200$. It was found that for these conditions beam intensity variations of the type shown in Fig. 10 were observed. This supports the earlier suggestion that the changes in beam intensity shown in Fig. 12 are not a result of a breakdown in skimmer pumping.

Similar trends have been observed with argon and nitrogen beams with the 0.1245-cm-diam orifice. If, as has been suggested, there is no breakdown in the cold skimmer and cold end wall pumping, another source of backscattered molecules must be responsible for the effects shown in

Fig. 12. Possibly these effects are orifice size dependent, since they have not been observed with the two smaller orifices. A characteristic of a free-jet expansion is that the radial spread of the flow is dependent upon (1) the ratio of source pressure to chamber background pressure and (2) the absolute size of the orifice. For all three orifices, there is not a significant difference in the pressure ratio which means that the nondimensional radial spread of the expansion should be approximately the same. However, the radial spread of the expansion from the large orifice is such that it can impinge upon the side walls of the chamber. The 20°K cryoliners mounted from the sidewalls of the chamber have three openings which expose 295°K surfaces: (1) the window opening, (2) a connecting pipe to the diffusion pump, and (3) a mounting block for the warm skimmer. The possibility exists that either one or all of these surfaces can attenuate the beam intensity in a similar manner to the warm end wall effect discussed earlier (Fig. 8). Modifications have been made to the chamber such that these surfaces are now shielded from the beam by 20°K surfaces. Thus, in the near future it should be possible to check the above hypothesis concerning scattering from warm side walls.

### 3.3 BEAM VELOCITY MEASUREMENTS

As has been noted earlier (Fig. 7), there is an increase in beam velocity at source conditions where condensation has occurred in the expanding flow. However, the data indicate that there are many factors which influence the velocity profile. For example, in Fig. 7 the data show that the monomer velocity is affected by the type of skimmer used. A comparison of velocity measurements obtained with a 20°K skimmer and a room temperature skimmer and end wall (Refs. 18 and 19) is made in Fig. 13. It is apparent from this comparison that scattering from the warm skimmer and end wall has a significant effect upon the measured velocity both before and after condensation has occurred in the flow.

It is of interest to note that the anomalous beam intensity values for the large orifice (Fig. 12) are associated with similar anomalies in the measured gas velocity (Figs. 12 and 14). This indicates that side wall scattering in the source section of the beam generation system can affect the beam intensity and beam velocity. Some beam velocity measurements obtained with room temperature $CO_2$ for the two types of skimmers and two orifice-skimmer separation distances (Fig. 14) support this. Since there seems to be a correlation between intensity attenuation and velocity profile distortion, and previous evidence indicates that the mechanical chopping wheel and associated collimator do

cause attenuation in beam intensity when condensation has occurred, then there is room for serious questions of absolute velocities measured by mechanically chopping condensed beams.

In addition to scattering in the source section and possible problems with a mechanical chopper, Fig. 15 shows some effects of varying the detector. Measurements of monomer velocity appear to be consistent up to the point where condensation is expected. Beyond this point the measured beam velocity depends on the mode of operation of the mass spectrometer, i.e., side-on or end-on to the molecular beam. A third velocity profile was obtained using an ionizing head directly attached to an electron multiplier (i.e., no mass filter).

It is felt that these effects can be qualitatively explained if one assumes that the condensed beam contains virgin monomers traveling at or above the theoretically calculated thermal velocity (excess velocity being caused by release of latent heat of condensation) and large clusters traveling at lower velocities. When these large clusters collide with any element of the beam system (skimmers, side walls, collimators, and choppers) the resulting debris is an effective scatterer of incident beam monomers (Fig. 8a). When fragmentation occurs in the ionizing region of the mass spectrometer, the resulting debris is composed of essentially monomers traveling at cluster velocity. The net effect of these interactions will be to bias the velocity profile to the slower moving debris monomers. Therefore, when interactions of this type occur the measured velocity will be less than the true beam velocity.

## SECTION IV
## CONCLUSIONS

As a result of a limited study of cryogenically cooled skimmers, Singh (Ref. 14) concludes, "The results of the present study revive all the old fears about the value of using a skimmed molecular beam to probe the free jet." Certainly the results of this investigation support this conclusion as it relates to noncryopumped molecular beam chambers.

1. For condensation-free flows, it has been shown that for a completely cryopumped chamber, i.e., skimmer, side wall, and end wall, beam velocity is not significantly affected by the positioning of a warm conical skimmer in front of the cryopumped end wall. However, small areas of nonpumping surface in the

cold end wall can attenuate the incident beam intensity significantly. For the case discussed herein, a beam attenuation of 75 percent was observed when a nonpumping annular ring, having inner and outer diameters of 14.5 and 23 cm, respectively, was mounted concentrically with the cryogenically cooled skimmer. This indicates that most skimmer studies to date have been dominated (as Bossel, Ref. 12, has noted) by end wall effects rather than by the skimmer alone, as has generally been assumed.

2. With the onset of condensation, large clusters are formed in the beam, and some beam attenuation is observed when a warm conical skimmer is located in front of the cryogenically cooled end wall. However, a nonpumping end wall has a more significant effect upon the attenuation of beam intensity. In both cases the attenuation is thought to result from an interaction of the debris resulting from cluster impact on these warm surfaces with the incident beam. With increasing source pressure, the clusters become so large and form such a large percentage of the total incident beam that the debris is no longer an effective incident beam attenuator.

3. Experimental evidence has been obtained which indicates that when the free jet expanding from the largest orifice of the present study impinged on some relatively small areas of nonpumping surface on the chamber side walls, the incident beam intensity was attenuated and the beam velocity was affected.

4. Monomer and dimer beam intensities have been shown to be affected by the impact of beam clusters on a warm collimator located in front of the mass spectrometer. Therefore, the possibility exists that the conventional mechanical beam modulating techniques in use in molecular beam systems may affect measurements of this type.

5. Gas velocity measurements have also been shown to be affected by warm skimmers, end walls, and side walls.

The data contained herein represent a summary of a developmental program to produce intense molecular beams in a wholly cryopumped chamber. It is considered that the results provide for a better understanding of the processes involved in the production of molecular beams than has been available to this time.

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# APPENDIX
# ILLUSTRATIONS

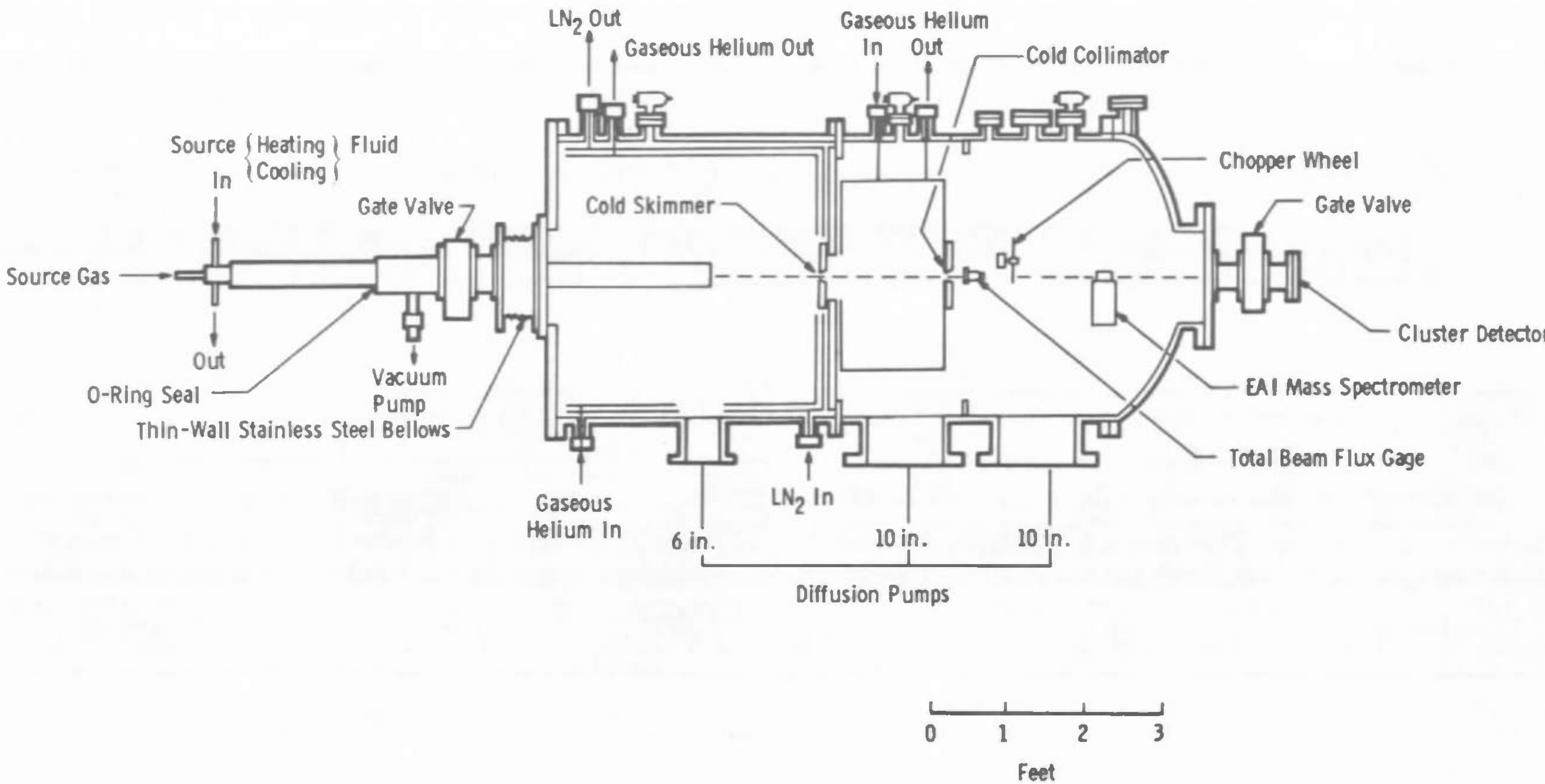



Fig. 1 Schematic of the Molecular Beam Chamber

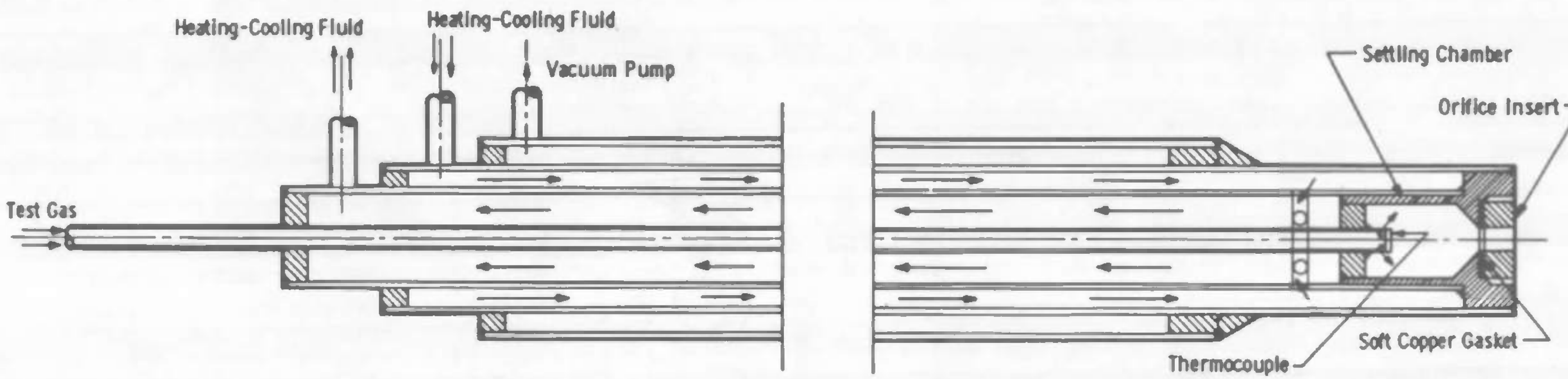
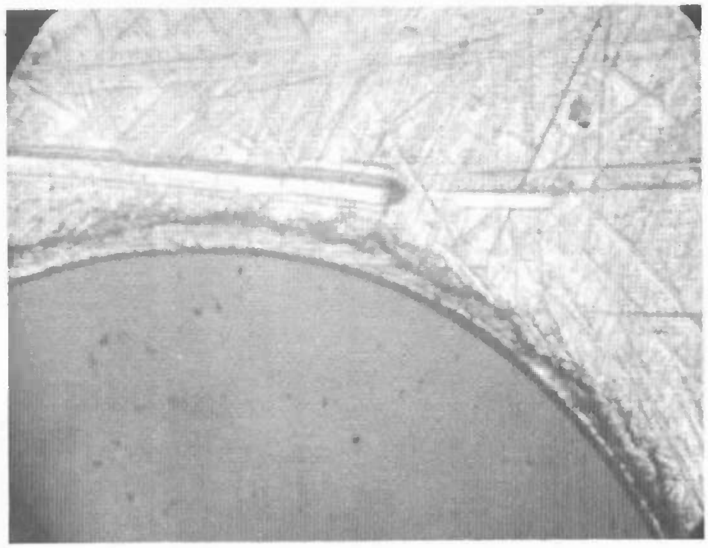



Fig. 2 Schematic of the Temperature Controlled Molecular Beam Source



Magnification 80

Magnification 320

Fig. 3 Orifice Used in Present Investigation

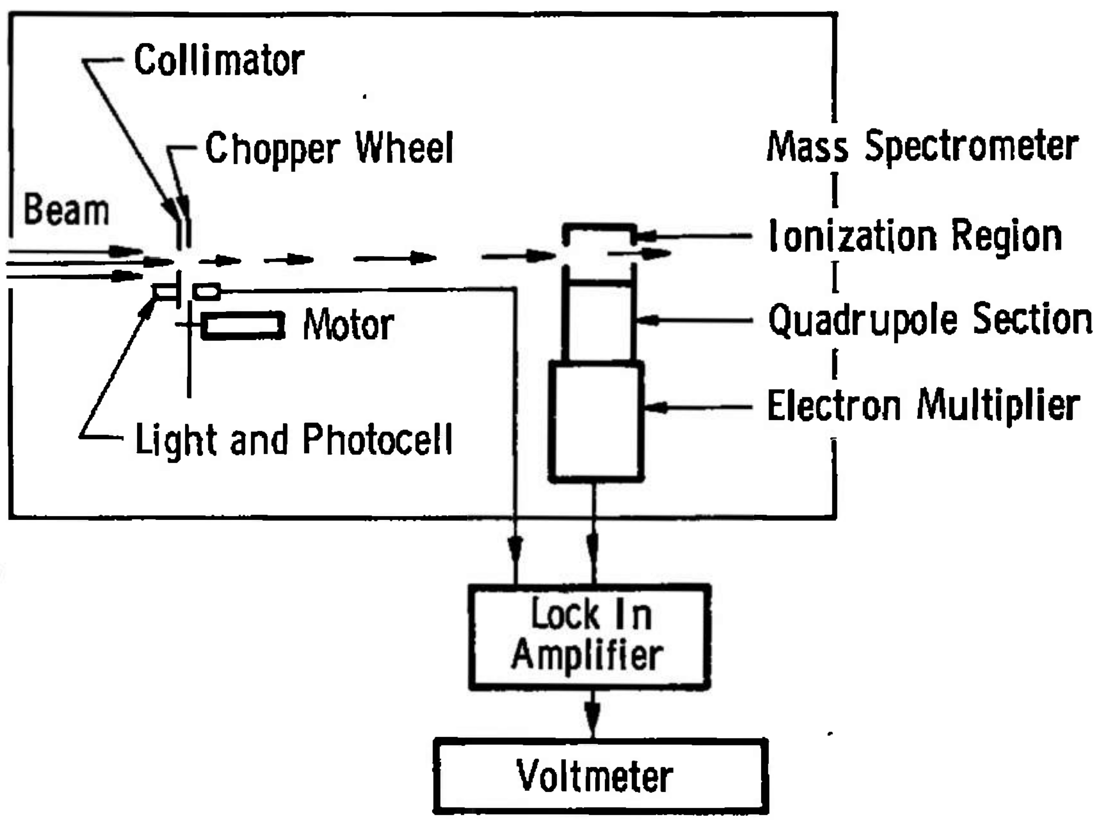



Fig. 4 Schematic of the Modulated-Beam Detection System Used to Measure Cluster Intensity

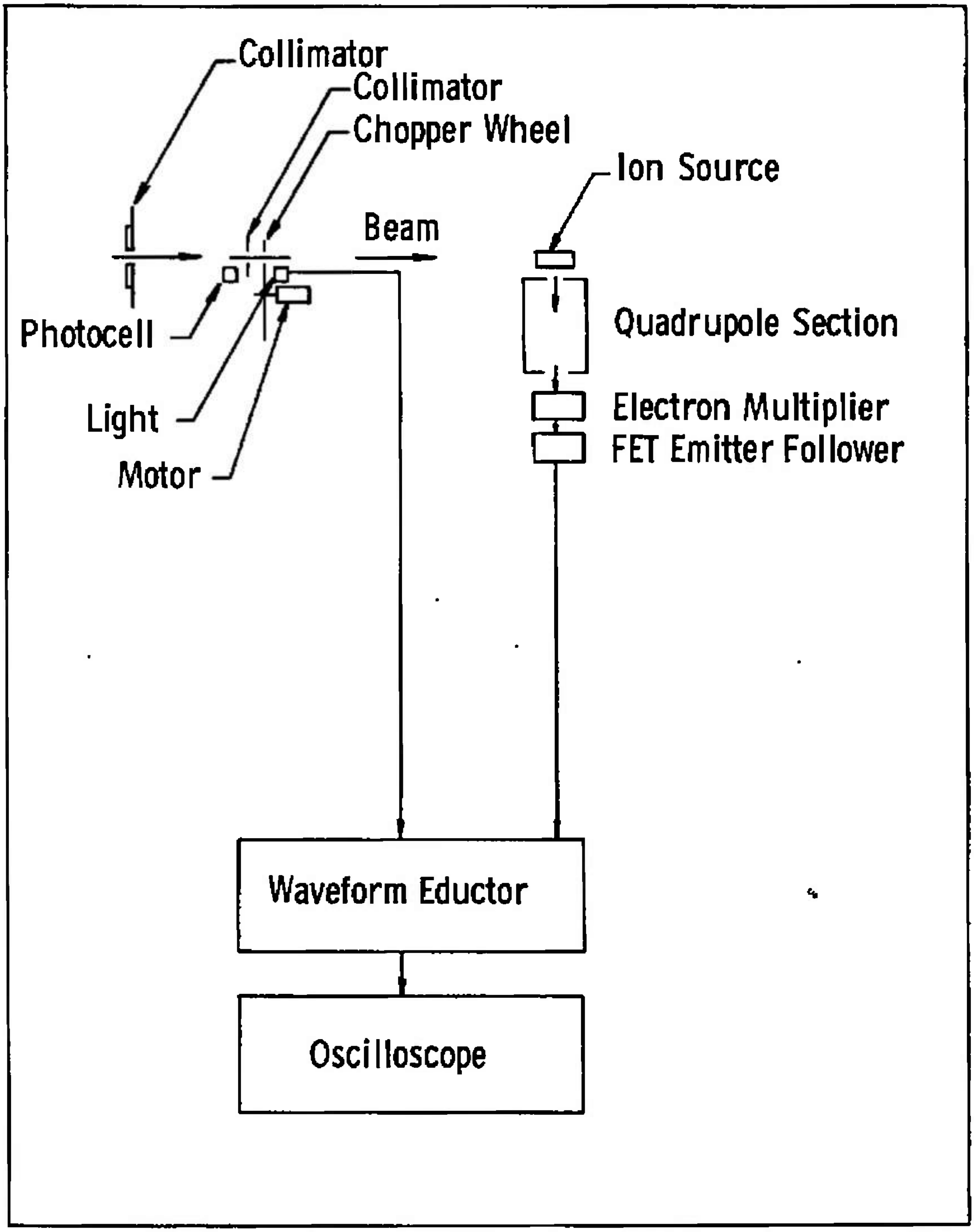



Fig. 5 Schematic of the Modulated-Beam Detection System Used to Measure Gas Velocity

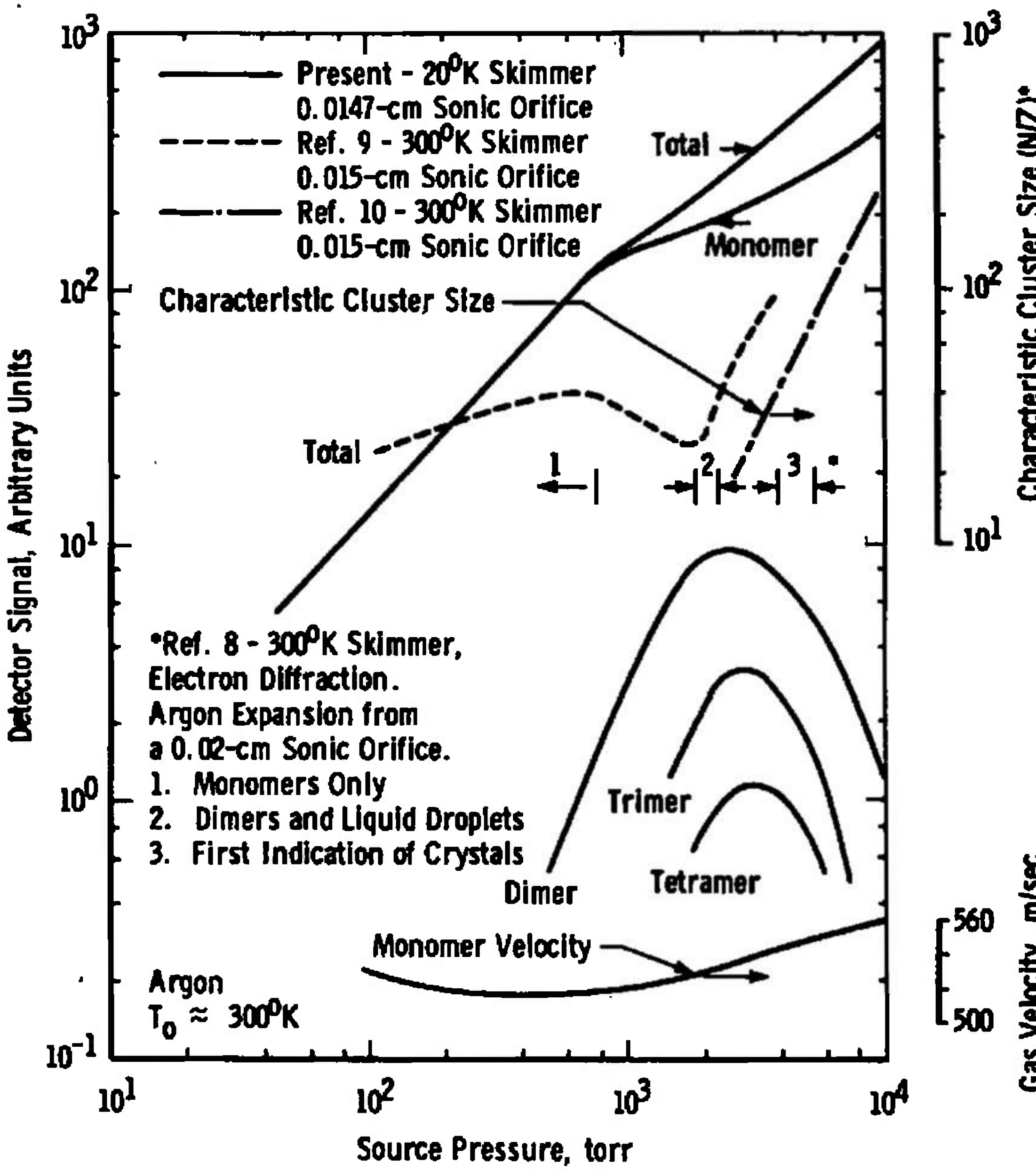



Fig. 6 Indicators of Condensation in Free-Jet Expansions

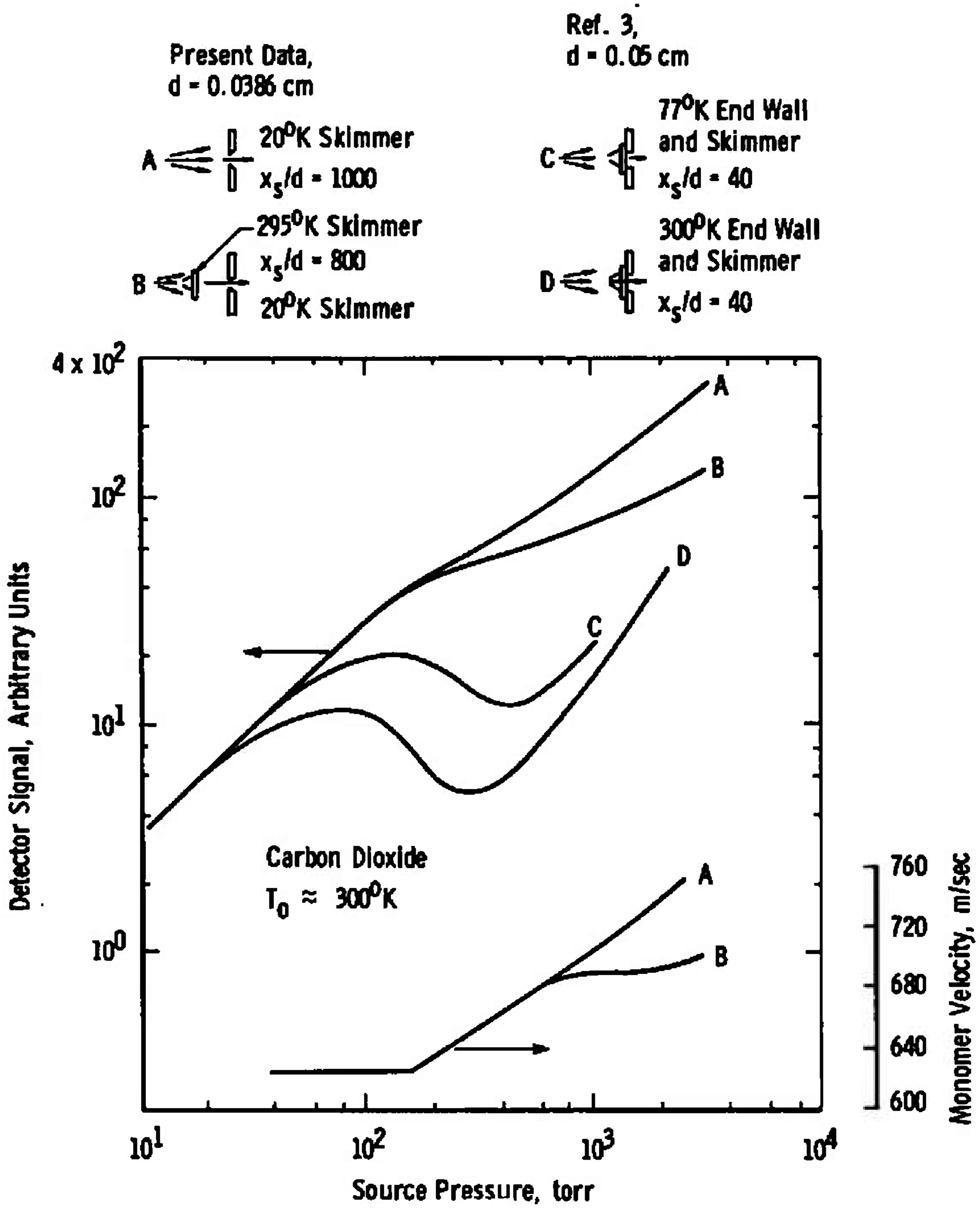
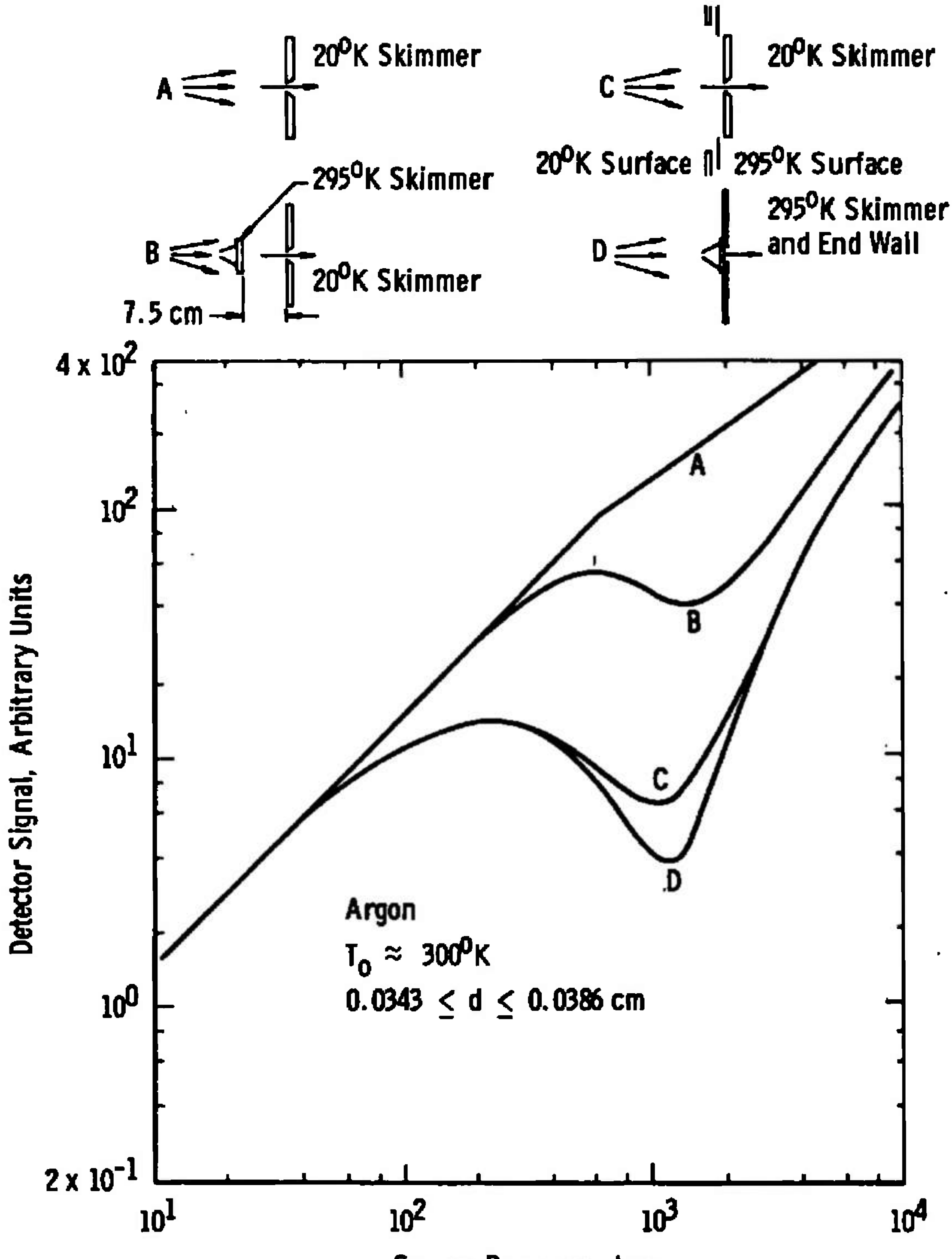
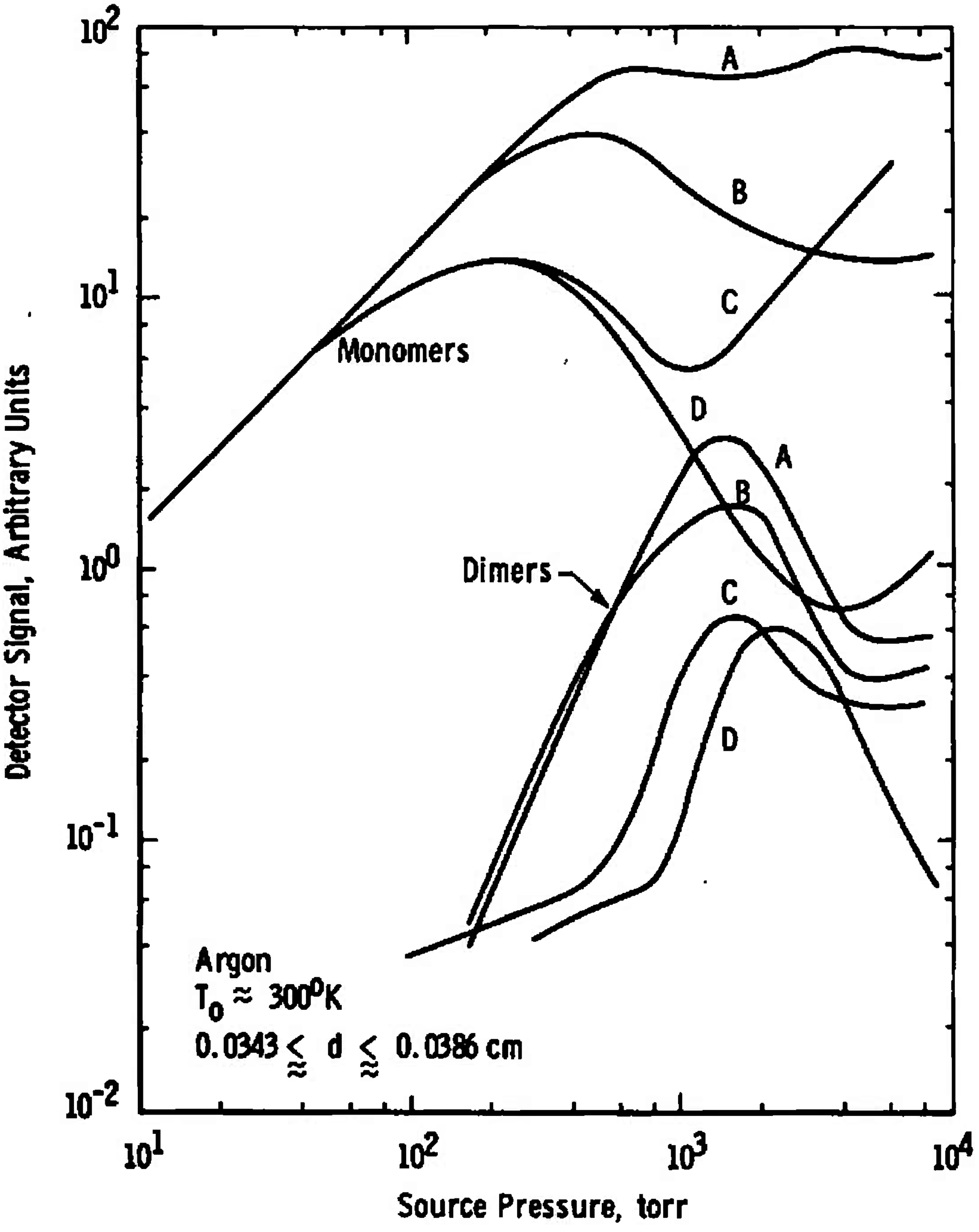



Fig. 7 Effect of Skimmer and End Wall Temperature on Beam Intensity for Carbon Dioxide




a. Total Beam Intensity

Fig. 8 Effect of Skimmer and End Wall Temperature on Beam Intensity for Argon




b. Monomer and Dimer Intensity
Fig. 8 Concluded

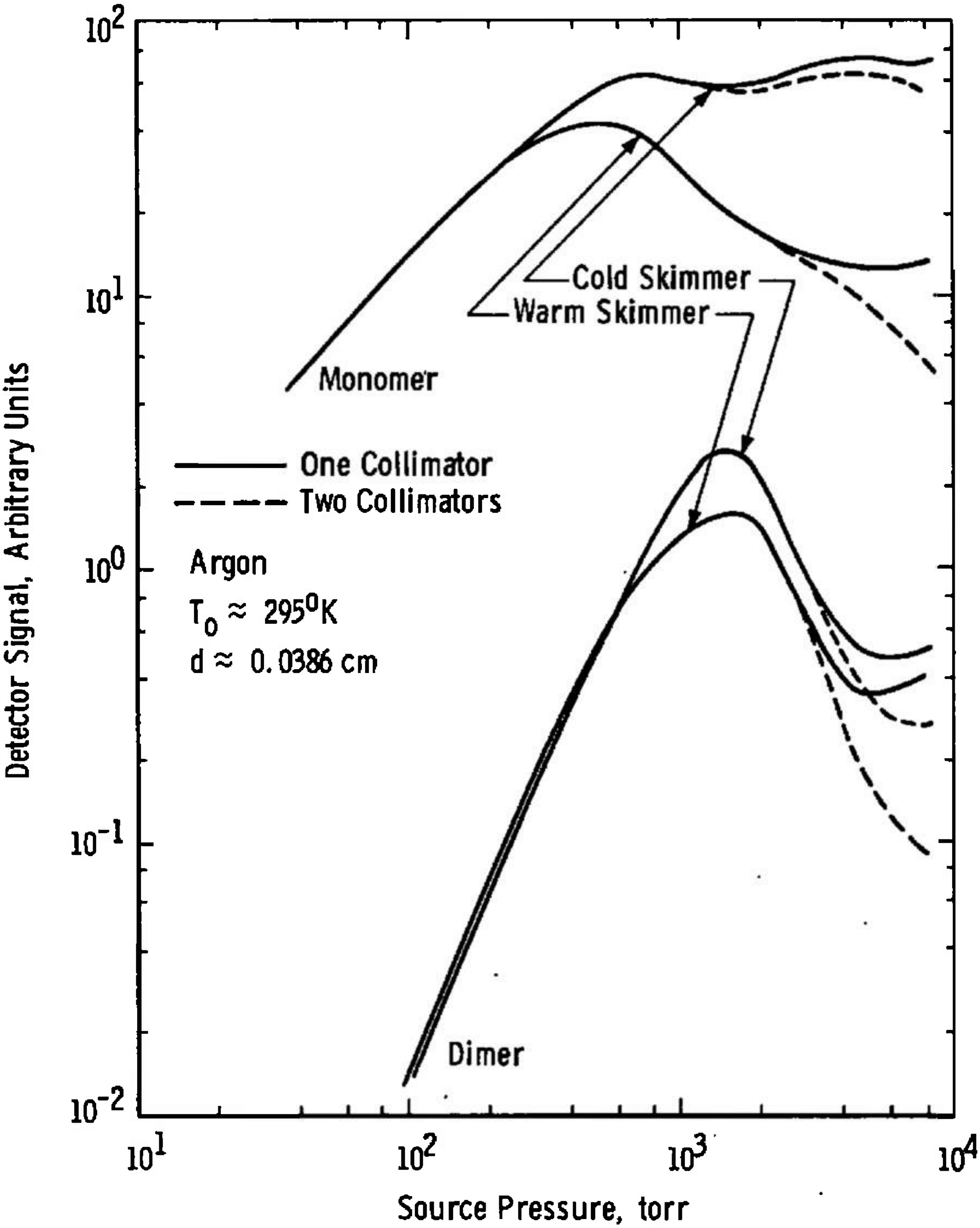



Fig. 9 Effect of a Warm Collimator in Test Chamber on Beam Intensity

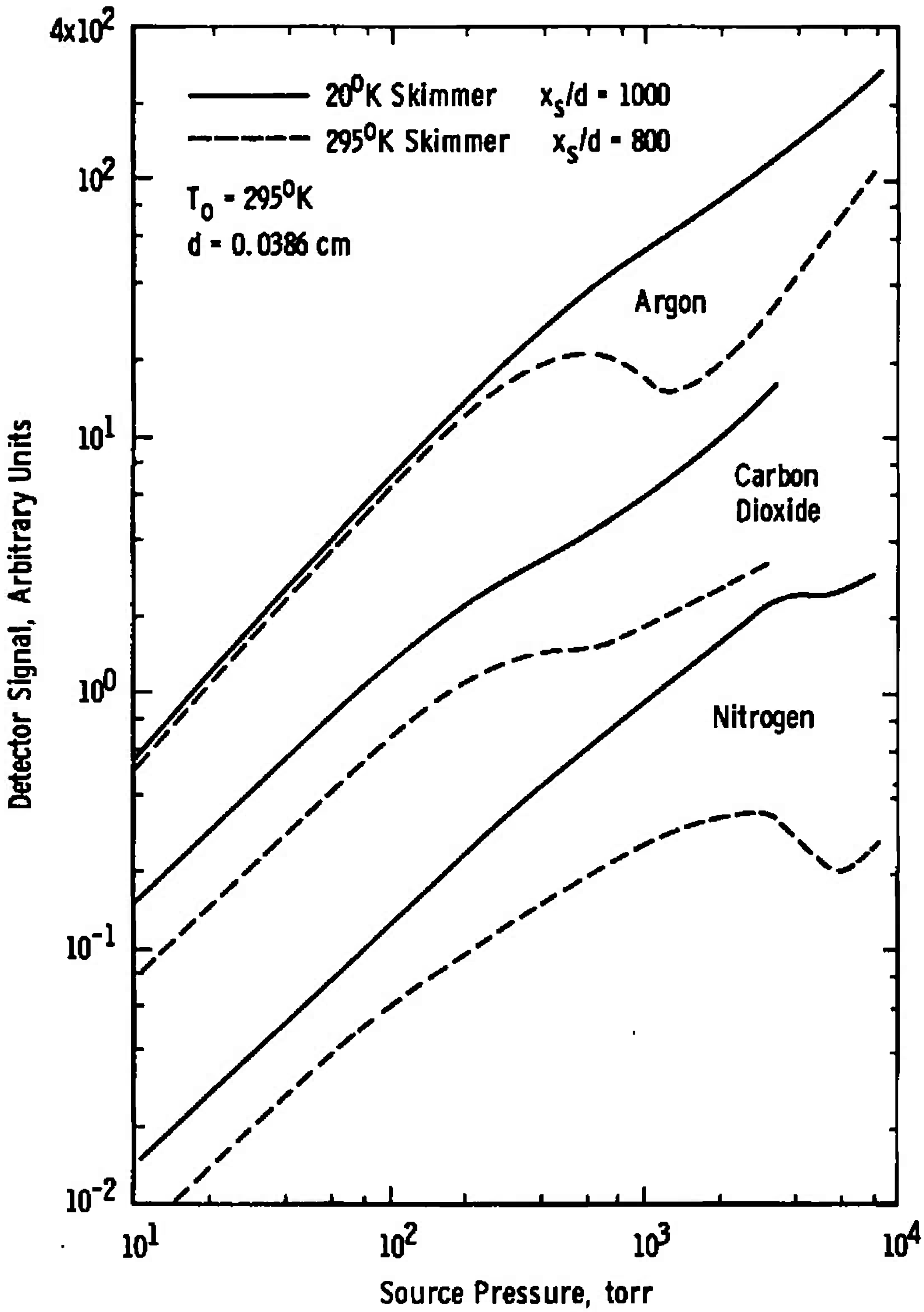



Fig. 10 Effect of Skimmer Temperature on Beam Intensity for Various Gases

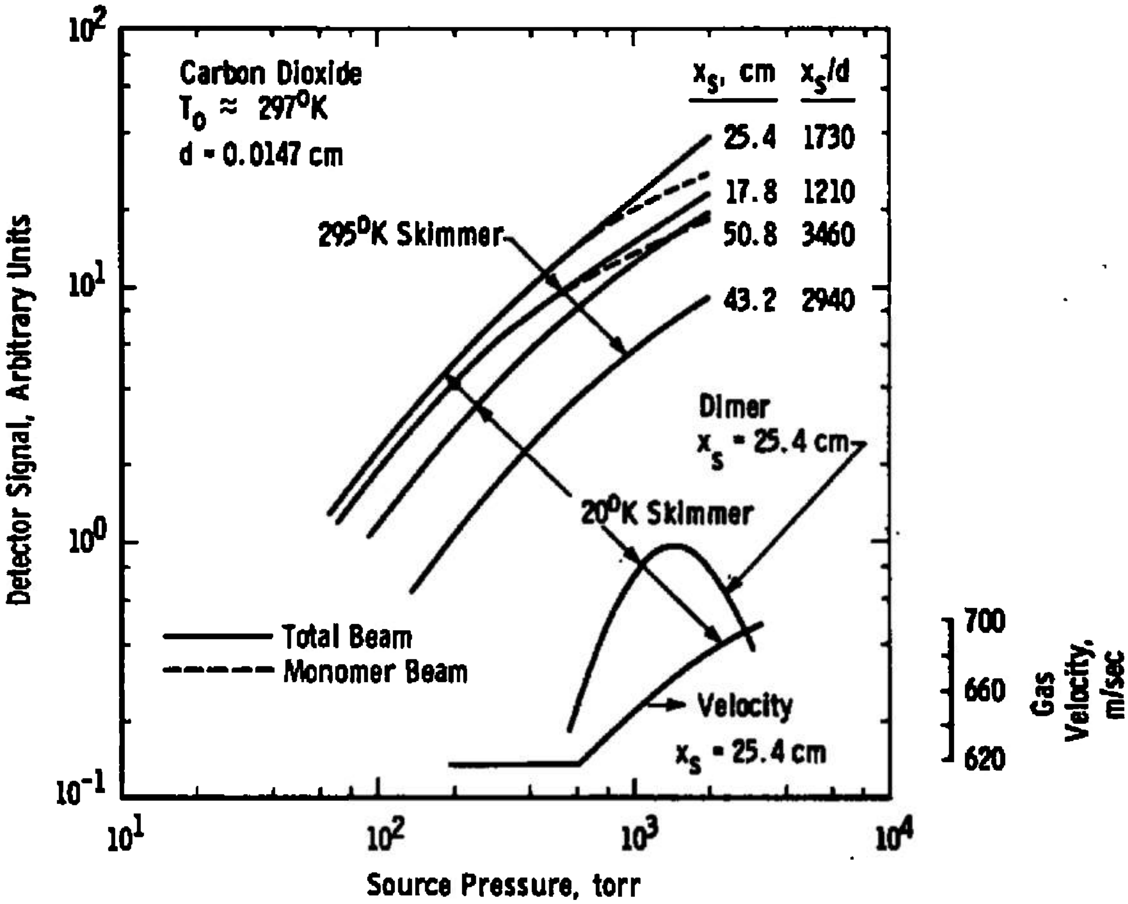



Fig. 11 Effect of Skimmer Separation Distance on Beam Intensity-Small Orifice

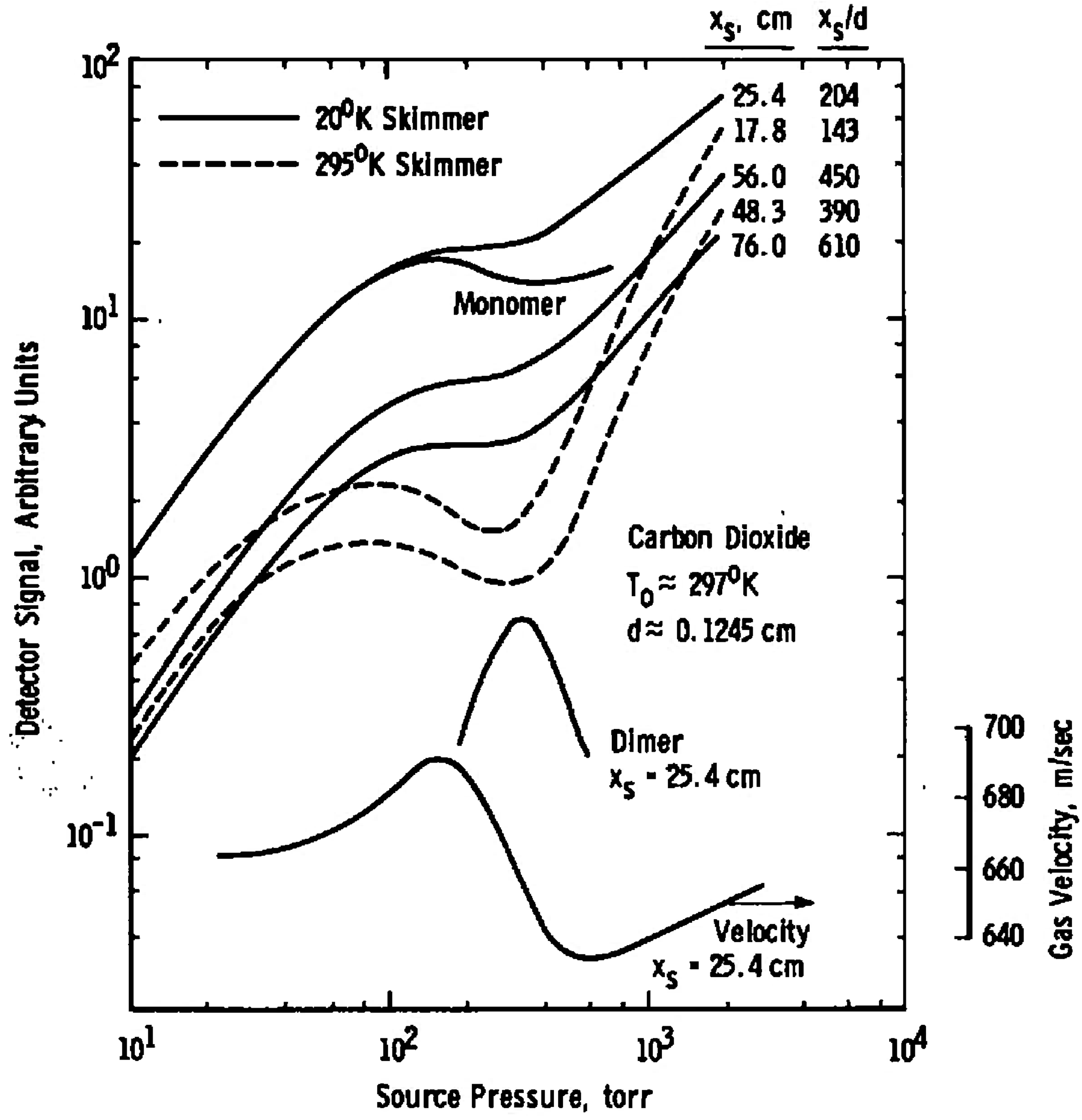



Fig. 12 Effect of Skimmer Separation Distance on Beam Intensity - Large Orifice

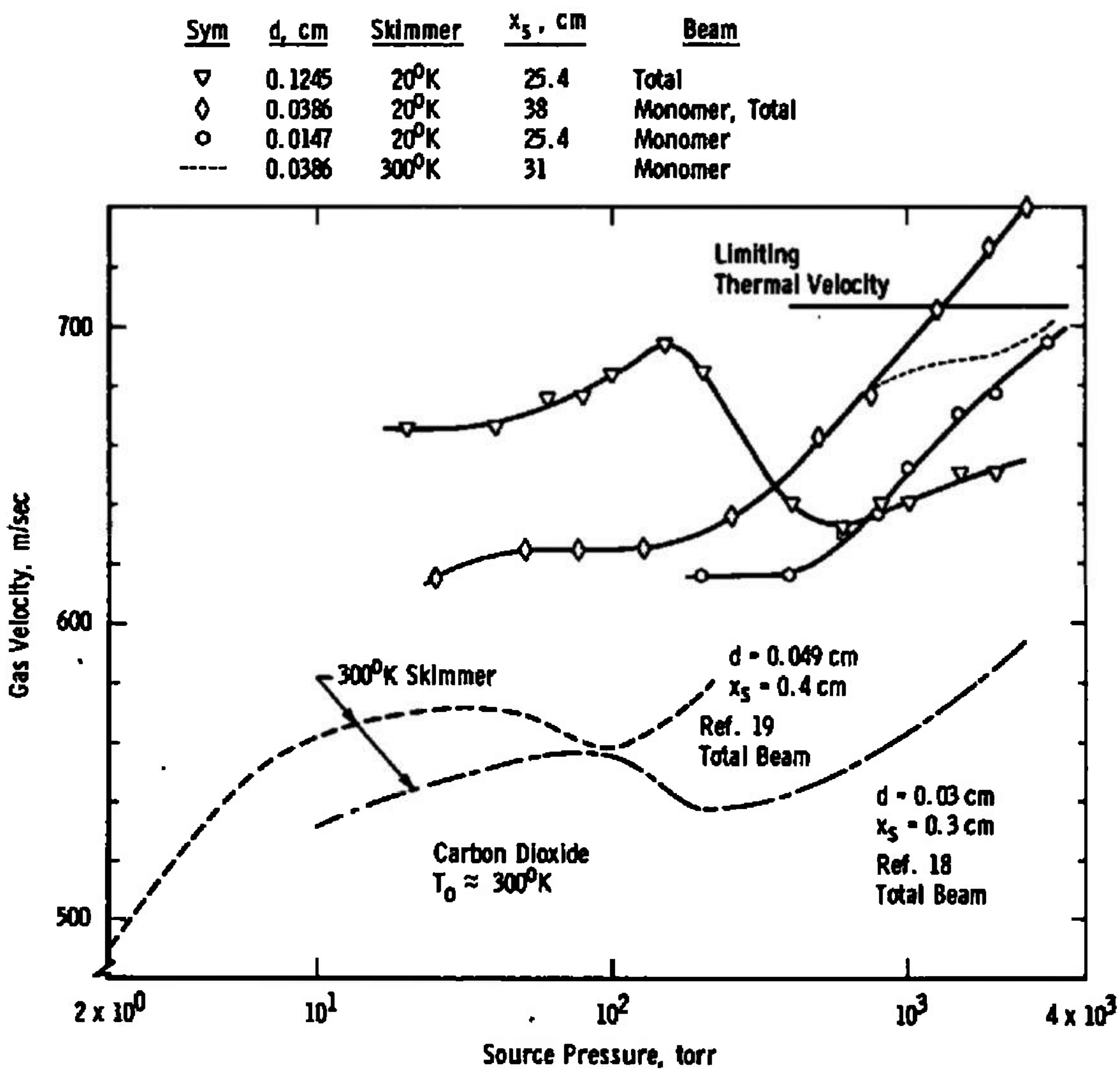



Fig. 13 Comparison of Carbon Dioxide Velocity Measurements

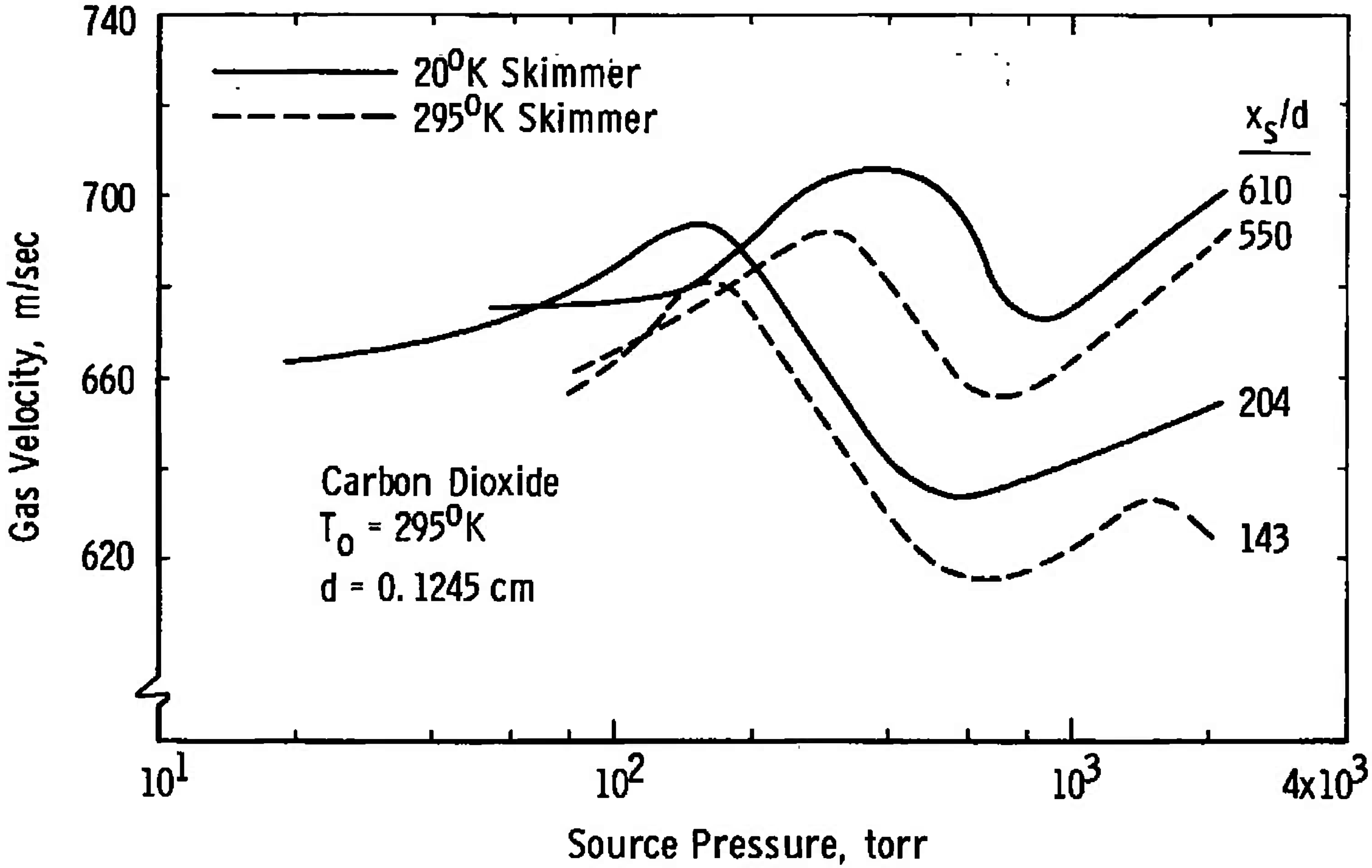



Fig. 14 Effect of Skimmer Separation Distance on the Measured Gas Velocity

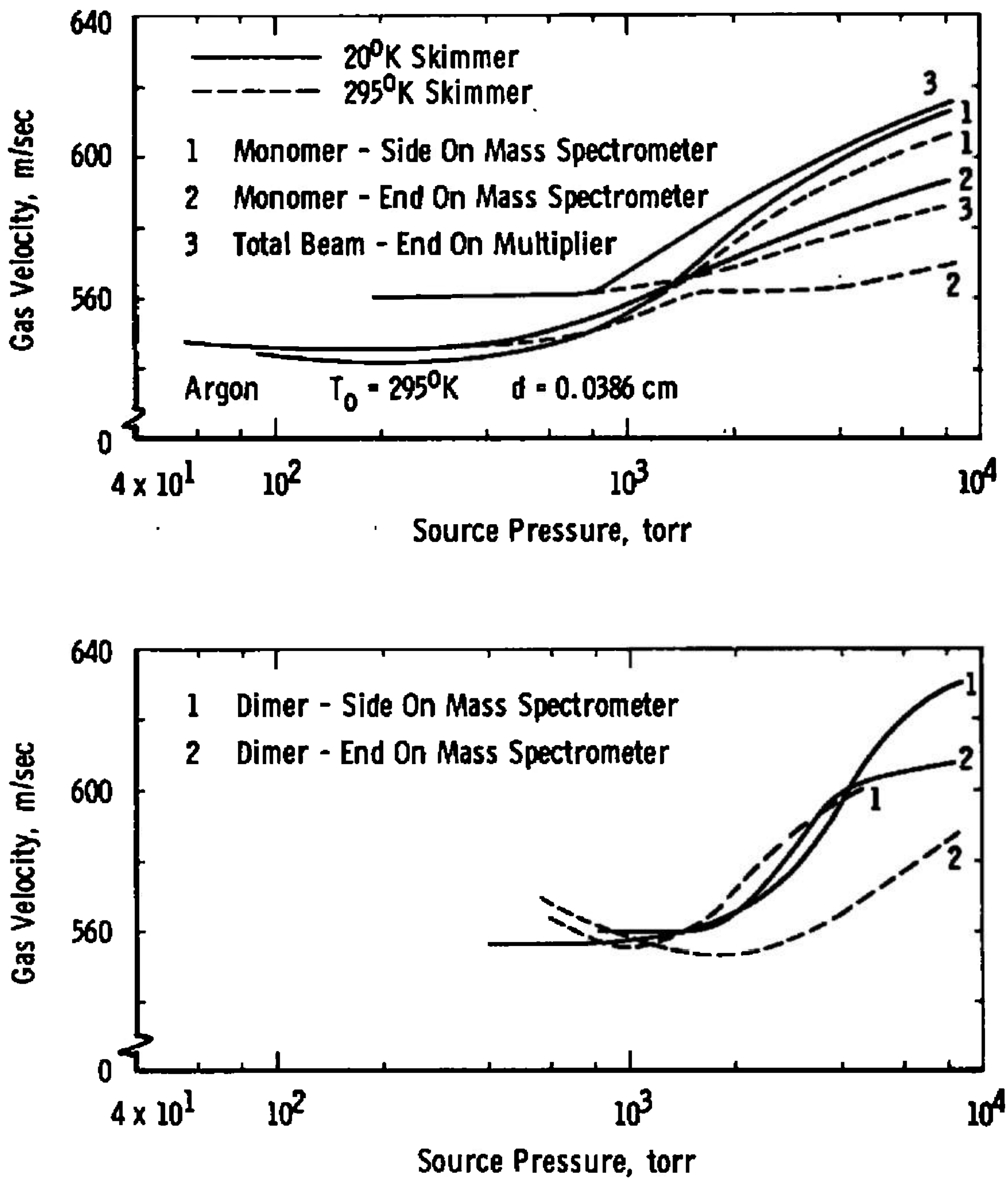



Fig. 15 Effect of Skimmer Temperature on Monomers, Dimers, and Total Beam Velocity

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13. ABSTRACT

Through the extensive use of cryopumping in the source, collimation, and test chambers of a molecular beam test facility, it has been possible to identify some of the factors affecting beam intensity in noncondensed and condensed flows. For noncondensed flows, the positioning of a warm conical skimmer in front of a cryopumped end wall does not appear to result in any significant skimmer interference effects on beam intensity. However, the location of a warm annular surface with inner and outer diameters of 14.5 and 23 cm, respectively, at the cryopumped end wall resulted in a significant attenuation of the incident beam intensity. This indicates that end wall scattering is a significant factor in determining molecular beam performance. With the onset of condensation, it has been shown that nonpumping skimmers and end walls reduce the incident beam intensity. This attenuation results from debris reflecting into the incident beam. However, for beams with significant condensation the total beam intensity is not affected as greatly. It is postulated that for source conditions where there is significant condensation, i.e., high source pressures, the incident beam attenuation will not be as great since the beam is composed of large clusters (possibly liquid droplets or crystals) that are not as easily scattered by the reflected cluster debris. Measurements of gas velocity in a condensed flow indicate that a nonpumping surface placed in the beam affects not only beam intensity but also the beam velocity.

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| skimmers | | | | | | |
| condensation | | | | | | |
| argon | | | | | | |
| nitrogen | | | | | | |
| carbon dioxide | | | | | | |
| performance | | | | | | |
| vacuum chambers | | | | | | |